

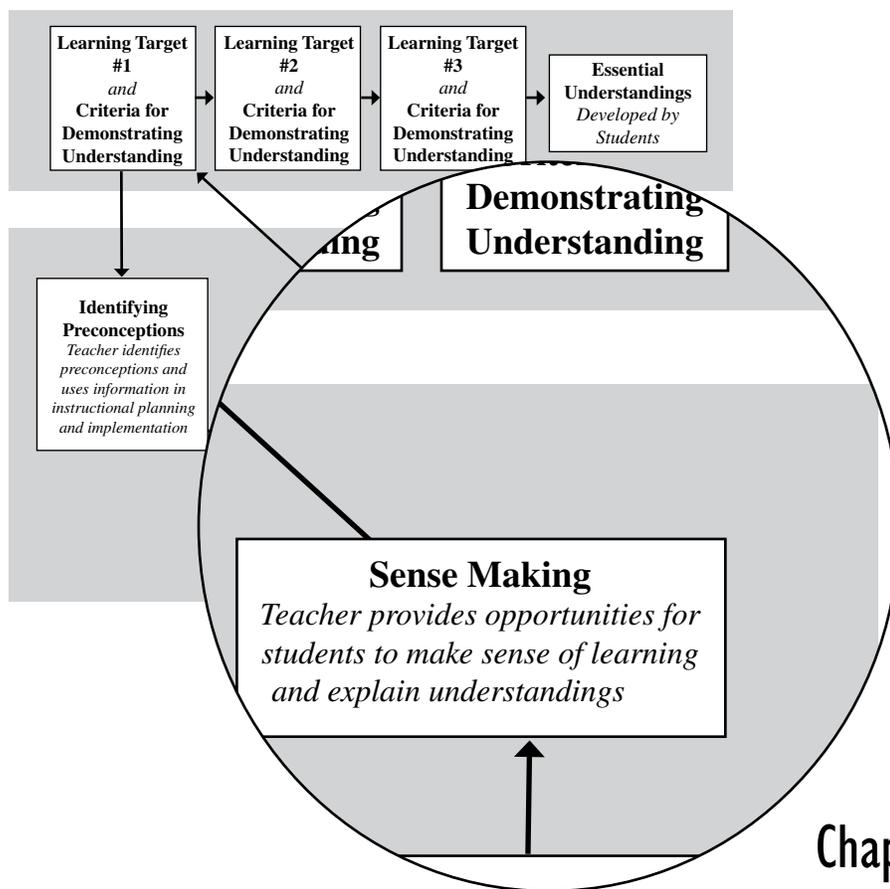
Instructional Planning Framework

Predictive Phase

The teacher determines the lesson's essential understandings, the sequence of learning targets that lead toward those understandings, and the criteria by which understanding is determined.

Responsive Phase

Building on the foundation of the predictive phase, the teacher plans for and implements instruction during the responsive phase, one learning target at a time.



Chapter 6

Molecular Genetics: Proteins and Genes

“Because molecular biology will continue into the twenty-first century as a major frontier of science, students should understand the chemical basis of life not only for its own sake, but because of the need to take informed positions on some of the practical and ethical implications of humankind’s capacity to manipulate living organisms.”

—*National Research Council 1996, p. 181*

Why This Topic?

At the same time that the media are filled with commentary about stem-cell research, gene therapy, and genetic modification of foods, few people understand the relationship between gene function, the production of proteins, and phenotype—a relationship essential to understanding each of those issues. Molecular genetics is a topic likely to have an immediate effect on and direct relevance to students’ lives in the 21st century, yet traditional teaching methods are not adequate to motivate and educate students about that topic (Eklund et al. 2007; Sinan, Aydin, and Gezer 2007).

Genetics is a difficult topic to understand (Bahar, Johnstone, and Hansell 1999; Mertens and Walker 1992) for a variety of reasons, including that students must integrate information from multiple levels of biological organization (Bahar, Johnstone, and Hansell 1999; Duncan and Reiser 2003; Kindfield 1994; Lewis and Wood-Robinson 2000). This is also the problem when it comes to the molecular basis of heredity because students must connect what happens at the molecular level during transcription and translation to the resulting cellular proteins and they must understand how that impacts the appearance and function of cells, tissues, and organisms.

These difficulties are compounded by the common approach to teaching genetics—that is, Mendelian inheritance is taught before DNA, and DNA is unconnected to the actions of proteins (Roseman et al. 2006). Also, passive instruction using lecture and textbooks, typical for this topic, relies on abstract, complex figures and chemical formulas, posing difficulties for typical high school students (Rotbain, Marbach-Ad, and Stavy 2005). Finally, “this area of science is moving so quickly that the majority of us lack appropriate content training” (Texley and Wild 2004, p. 89).

Overview

In this chapter, we focus conceptually on the connection between genotype and phenotype, specifically the role of genes and proteins in that connection. We also consider the importance of proteins to the work of cells and the impact of proteins on the structures



Topic: Factors affecting population growth
Go to: www.scilinks.org
Code: HTB007

Topic: Genotypes
Go to: www.scilinks.org
Code: HTB008

Topic: Phenotypes
Go to: www.scilinks.org
Code: HTB009

and functions of organisms. We do not cover the details of transcription and translation but, instead, stress the importance of the process in the production of proteins essential to life. Nor will we discuss regulation of gene expression. In terms of the Instructional Planning Framework, our focus is on sense making and demonstrating understanding. (*Note: All tables are grouped together at the end of the chapter, beginning on p. 183. They are followed by Recommended Resources and Endnotes.*)

At this point, meet Mr. Adams, a teacher who has tried in many ways to improve his instruction yet is met with less than adequate student understanding (Figure 6.1). We'll use Mr. Adams's context as we delve into the biological content of this chapter and sense making and demonstrating understanding.

Figure 6.1

Case Study About Protein Synthesis Instruction

Mr. Adams worked for years to improve his students' understandings about protein synthesis. He took a course on technologies appropriate to molecular genetics, attended a workshop on multiple intelligences, and learned through district professional development about cooperative learning and reading in the content area. He even completed a graduate degree with a focus on molecular biology. In his classroom, he used a good combination of interactive lectures and hands-on experiences. His students completed activities that included laboratory-based activities and simulations. He thought he understood what his students knew and the things that were most difficult for them. But regardless of his attempts, they still struggled to understand the central importance of protein synthesis. What might be the problem?

Instructional Planning Framework: *Predictive Phase*

We limit coverage of the *predictive phase* in this chapter to its application in a lesson about molecular genetics. First though, we revisit *Science for All Americans* to remember our end target, the expectations for adult science literacy (Figure 6.2).

Figure 6.2

Adult Science Literacy Expectations for Molecular Genetics

"The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins. Protein molecules are long, usually folded chains made from 20 different kinds of amino acid molecules. The function of each protein depends on its specific sequence of amino acids and the shape the chain takes as a consequence of attractions between the chain's parts. Some of the assembled molecules assist in replicating genetic information, repairing cell structures, helping other molecules to get in or out of the cell, and generally in catalyzing and regulating molecular interactions. In specialized cells, other protein molecules may carry oxygen, effect contraction, respond to outside stimuli, or provide material for hair,

nails, and other body structures. In still other cells, assembled molecules may be exported to serve as hormones, antibodies, or digestive enzymes.

“The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. This code is virtually the same for all life forms. Thus, for example, if a gene from a human cell is placed in a bacterium, the chemical machinery of the bacterium will follow the gene’s instructions and produce the same protein that would be produced in human cells. A change in even a single atom in the DNA molecule, which may be induced by chemicals or radiation, can therefore change the protein that is produced. Such a mutation of a DNA segment may not make much difference, may fatally disrupt the operation of the cell, or may change the successful operation of the cell in a significant way (for example, it may foster uncontrolled replication, as in cancer).” (AAAS 1989, pp. 63–64)

Using these expectations of adult science literacy as our ultimate goal, we use the procedures outlined in Chapter 3 to determine the conceptual targets, a logical learning progression, and the criteria to demonstrate understanding (Figure 6.3).¹

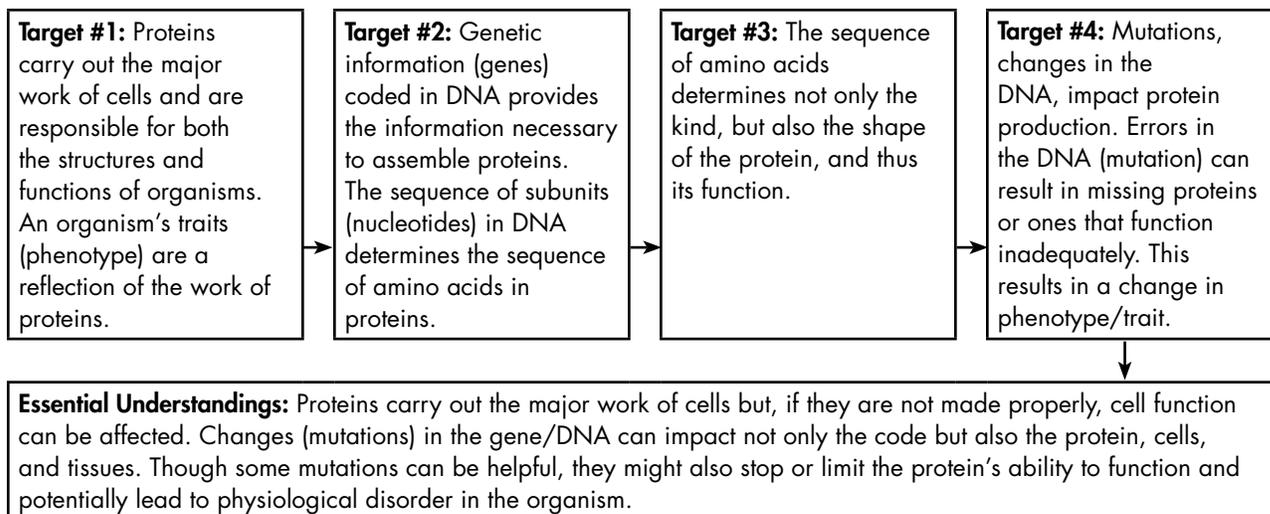
Figure 6.3

Planning in the Predictive Phase

1. Identify the essential understandings for the lesson.
 - a. Begin with the descriptions of adult literacy to determine an anchor goal.
 - b. Consider the middle school and high school standards and benchmarks.
 - c. Optional: Study existing research on learning progressions. A good resource (www.project2061.org/publications/2061Connections/2007/2007-04a-resources.htm) is found in the 2061 Connections online newsletter (AAAS 2007a).
 - d. Dig a bit deeper and think about the concepts included in the standards.
 - e. Decide what is essential and what can be pruned.
2. Develop a logical sequence of learning targets for the lesson.
 - a. Consider the middle school science experiences students should have had.
 - b. Outline the key ideas embedded in the high school standards and benchmarks.
 - c. Sequence the key ideas in a way to build student understanding.
 - d. Consider connections from one lesson to the next.
3. Identify the criteria for demonstrating understanding. (*Note:* Steps b and c are completed later, after a review of research.)
 - a. Identify one criterion for each Learning Target.
 - b. Identify one criterion for your selected standards-based strategy (Inquiry, HOS, or NOS).
 - c. Identify one criterion for your selected metacognitive strategy

The work completed during the process in Figure 6.3 was added to the Teacher Work Template (Table 6.1, p. 183) for the topic “proteins and genes.” This template lays the foundation for this lesson. Also review the learning sequence and how it leads to the essential understandings for this topic during the *responsive phase* (see Figure 6.4).

Figure 6.4

Proteins and Genes Learning Sequence**Reflection and Application**

We have implemented the *predictive phase* process (Figure 6.3) in Chapters 4, 5, and this one. Reflect, once again, about this process as related to “proteins and genes.”

1. How have you taught this topic in the past?
2. In what ways does your past instruction align with the work in the *predictive phase* for this topic? In what ways is it different?
3. Are there changes you might make in your instruction based on this information?

Instructional Planning Framework: *Responsive Phase***Identifying, Eliciting, and Confronting Preconceptions**

Recall that in Chapter 4 we focused on how to learn about research-identified student misconceptions (also see Figure 6.5). The Instructional Tools on pages 33–87 show how to select appropriate strategies to determine our own students' preconceptions. In Chapter 5, we built on the Chapter 4 example of identifying strategies to elicit and confront student preconceptions (steps #4–#10 in Figure 6.5). We completed all of the steps outlined in Figure 6.4, and added them to the Teacher Workshop Template (Table 6.1 on p. 183) for the topic “proteins and genes.”

Figure 6.5

Planning in the Responsive Phase

Learn About Research-Identified Misconceptions

1. Review *Benchmarks for Science Literacy* (AAAS 1993) for misconceptions discussed there. Chapter 15 of the book includes research findings organized by benchmark. If you do not have a copy of the book, you can read the book online at www.project2061.org/publications/bsl/online/index.php?txtRef=&txtURIId=%2Fpublications%2Fbsl%2Fonline%2Findex.
2. Complete a web search for misconceptions on the selected topic. Simply run a search for your topic and misconceptions (e.g., “photosynthesis + misconceptions”). If you run your search at Google Scholar (<http://scholar.google.com>), you will gain access to numerous resources. In some cases you will only access the abstract, but in others you will find the entire document. This process is more time-consuming than step #1 but yields additional resources.
3. This step is the most direct way to access a summary of misconceptions, but it requires that you have a copy of *Making Sense of Secondary Science: Research into Children’s Ideas* (Driver et al. 1994). The book is outlined by topic and provides a rich summary of research on children’s ideas about these topics.

Strategy Selection: Identify, Elicit, and Confront Preconceptions

4. Use the Instructional Strategy Sequencing Tool in Chapter 2, page 29, to identify possible strategies to identify student preconceptions, as well as strategies to elicit and confront those preconceptions. Finally, identify metacognitive and standards-based strategies to review.
 5. In Chapter 2 find the strategies in the three Metacognitive Strategy Tools (Instructional Tools 2.2–2.4), the three Standards-Based Strategy Tools (Instructional Tools 2.5–2.7), and the seven Sense-Making Strategy Tools (Instructional Tools 2.8–2.14).
 6. Carefully review the research and application recommendations for each of the identified strategies.
 7. Determine several strategies that fit well with the particular content you are teaching.
 8. Select one metacognitive strategy, one standards-based strategy, and two or three sense-making strategies for use in your lesson (recall that these will be used to differentiate instruction and to provide further instruction if formative assessments indicate that students do not understand the learning targets).
 9. Determine one criterion to demonstrate understanding for each of your metacognitive and standards-based focuses. Add these to the existing criteria in the Teacher Work Template.
 10. Review the resources listed in the Instructional Tools to more fully understand the strategies and to determine what they might look like in application.
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It is important that you study the completed Teacher Work Template (Table 6.1, p. 183). It shows the foundation for our upcoming work, for the selection of strategies that will help students make sense of their experiences, and for helping us understand what our students have really learned from the experiences.

Before proceeding to our discussions of sense making and demonstrating understanding, we share some information related to proteins and genes that we found during our review of the research. Here are the keys ideas:

- Student understanding of proteins, genes, the connection between them, and genomes all increased when teachers did the following: integrated proteins into the same context as genes; introduced the importance of proteins before introducing genes; and scaffolded students' written explanations of a trait at the levels of gene, protein, cell, tissue, and organisms (Eklund et al. 2007).
- Students' limited understanding of the specific contexts at the cellular, tissue, and whole organism levels may be a reason students struggle to make a connection between protein and trait. The examples teachers use should be simple and familiar to students. In addition, activities should be spread throughout the lesson not just used at the end of the lesson (Eklund et al. 2007).
- Lewis and Kattmann (2004) recommend using sickle-cell anemia as an example that links the gene, the structure/function of the gene product, and the resulting phenotype. Other research recommends that the teacher cover a number of different disease traits as well as nondisease traits to provide context (Eklund et al. 2007).
- Attention should be paid to confusing terms (*proteins* and *amino acids*, *gene*, *mutation*) but not to unnecessary words (*transcription* and *translation*) (Eklund et al. 2007).

Reflection and Application

Take a moment to reflect on the process of identifying, eliciting, and confronting pre-conceptions for "proteins and genes."

1. We identified "proteins and genes" as a hard-to-teach topic. What, in your opinion, makes it hard-to teach?
2. Based on the research we summarized in the bullet list above and in Table 6.1, what might you do differently in your current lesson on proteins and genes?
3. How well would the strategies work in your classroom? Would you need to modify them to work in your context? If so, what might you do?

Sense Making: Strategies to Address Preconceptions

We looked briefly at sense making in Chapter 5, but we are now ready to more clearly define how to select and implement sense-making strategies. This is the primary focus of this chapter. We also look at how students demonstrate understanding through formative assessments and how we can use those assessments to inform instruction. It is here that we also consider the iterative nature of the *responsive phase* of the Instructional Planning Framework.

First, what do we mean by *sense making*? Eliciting and confronting students' pre-conceptions will not, by itself, promote conceptual understanding. Effective instruction requires that students make sense of the ideas with which they grapple, connecting what they already understand with the learning intent of the lesson, linking the ideas to the larger scientific body of knowledge, organizing that knowledge, and applying the ideas to new contexts. It is not likely that students will make all these connections by themselves, so it is important that teachers facilitate this process (Banilower et al. 2008). Sense making should occur throughout the lesson, even as teachers elicit and confront student pre-conceptions. The lesson in this chapter uses teacher questioning, group discussions, student reflection, and more.

However, our lesson on proteins and genes (as we have developed it so far in this chapter) does not yet require interactive activities followed by sense making. Recall our case study of Mr. Adams's biology class. His instruction, similar to our lesson so far, does not include adequate opportunities for student sense making. We need to consider strategies that will help Mr. Adams and other teachers like him to introduce sense making effectively.

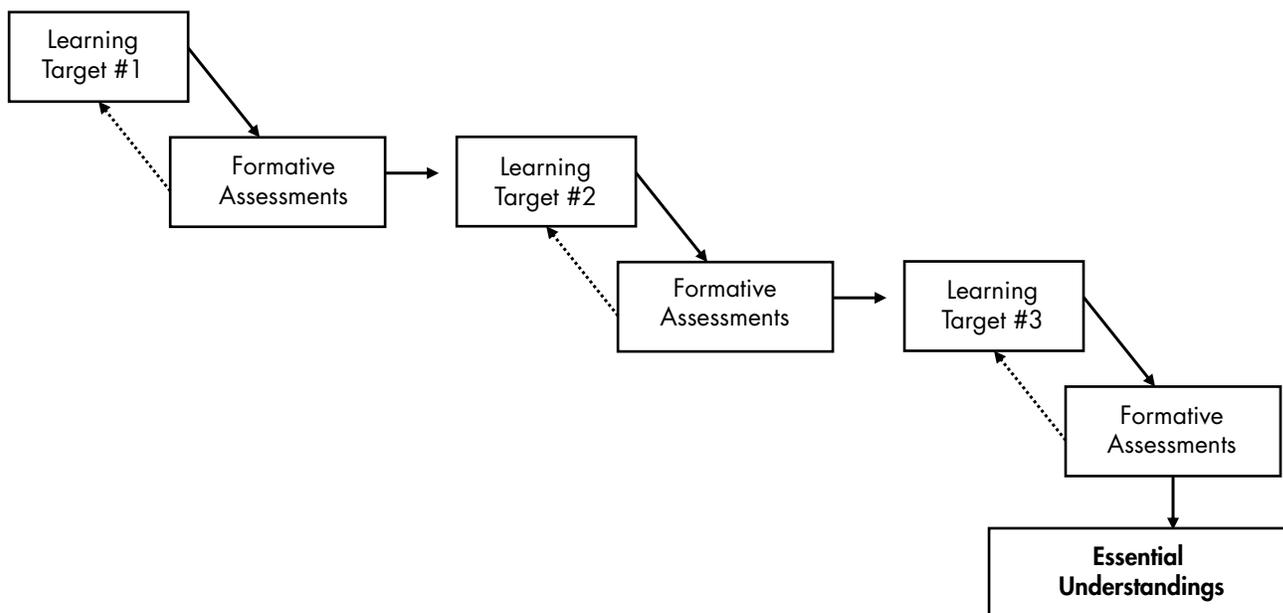
We use the same process to identify effective sense-making and formative assessment strategies that we did to identify strategies to elicit and confront pre-conceptions (see Figure 6.5, steps #4–#7). Step #4 asks you to look at the Instructional Strategy Sequencing Tool (Instructional Tool 2.1, p. 29). Take a moment to review this tool once again. In that tool, under "Sense Making," you will find the following four categories:

1. Perceiving, interpreting, and organizing information
2. Connecting information
3. Retrieving, extending, and applying information
4. Using knowledge in relevant ways

These categories support sense making. It is from these categories that teachers should select strategies. And, we suggest, the further teachers move through the instructional learning sequence, the more they should move to the right among those four categories

Demonstrating Understanding

In this sample approach to the topic and the application of the Instructional Planning Framework, we need to determine the best formative assessments. We must also consider the iterative nature of the *responsive phase*. Up to this point in the book we have modeled the process of *planning* for instruction. Now we need to think about how formative assessments might inform our *actual implementation of the plan*. What if our formative assessments during Learning Target #1 in Table 6.1, page 186, indicate that students just didn't "get it" or understood part of the concept but not all? Instead of a linear path through the lesson—charging ahead because we constructed the lesson in

*Figure 6.6**Planned Learning Sequence**Implemented Learning Sequence*

that way—we need to give students other experiences with the same content so that they have additional opportunities to learn.

What does it look like when we “double back” in our lesson? Take a look at Figure 6.6. Notice the “planned learning sequence,” similar to the one in our Instructional Planning Framework (Figure 1.1, p. 6). It is linear in nature and appears quite predictable. However, as teachers know, things are not always so clear-cut during implementation. Now, refer to the “implemented learning sequence.” The formative assessments might indicate a need to provide additional instruction for some or all of the concepts for the Learning Target. On the other hand, it is possible that we could proceed directly

from the formative assessments to Learning Target #2 if students demonstrate clear understanding of Learning Target #1. This is true for each of the learning targets and demonstrates the iterative nature of the responsive phase of our framework.

Sense Making and Demonstrating Understanding for the Learning Targets

Now we are ready to determine the best sense-making strategies for each learning target. Review the sense-making strategies in Instructional Strategy Sequencing Tool 2.1 (p. 29), both linguistic and nonlinguistic representations, and consider which best suit this lesson. It is important to keep in mind that the strategies and activities chosen for Learning Target #1 (student research using text and web resources) are likely to be quite different from those used in Learning Targets #2–#4 (using and interpreting dynamic models).

Learning Target #1 (Table 6.1, p. 185)

It is appropriate to focus on linguistic representations for this learning target because we chose to elicit and confront student preconceptions in ways that require students to read for information (as well as comprehension) as they research a particular disorder. Linguistic representations should help support students' reading, the organization of their thinking as they read and gather information, and the representation of their understanding when they present, in some way, what they have learned. Our chosen sense-making activities employ individual learning logs with four components:

1. Two-column notes (an informational text strategy for active reading that students use as they research their topics. See <http://printables.familyeducation.com/skill-builder/graphic-organizers/51680.html>).
2. Tree maps (a thinking-process map) to help students sort their information into various organizational levels and consider how each level is impacted
3. Individual reflections on the reading and writing processes, students' emerging content understandings, and any questions they have
4. Individual written explanations to summarize students' understanding of how their disorder impacts the various levels of organization in the human system

Small groups then share and critique their individual summaries from their learning logs, discuss their findings, and summarize their thinking as a group. They then prepare a poster to share with the class, describing what they learned. Posters are hung around the room and used in a round-robin session during which student groups visit other posters to critique, look for similarities and differences among the posters, and pose questions. Finally, the teacher facilitates a class discussion that summarizes the thinking and generates questions, making a record of thinking on poster paper or a SmartBoard. Summarizations and questions are retained for ongoing thinking throughout the lesson.

The selected sense-making strategies also serve nicely as formative assessments. Two-column notes, learning logs, and tree maps are reviewed to determine students' understandings. The teacher provides comments in student journals that are designed to provoke further thinking, work, and learning. Questions and probes during student group work also further student understanding and inform the teacher about student conceptions. Student posters and presentations are assessed for clarity and accuracy, and poster presentations allow teachers and peers to probe student thinking and assess understanding.

Remember that though we outline the assessments separately to bring them to your attention, they occur as close to the sense-making experience as possible, and in the case of questioning and probes, they occur concurrently. These “in the moment” assessments continually probe student understandings and provide information to modify instruction, as needed. In addition, as students become more self-aware during the sense-making process, self-reflection and peer assessments deepen understanding. The close interactions of sense making, reflection, and formative assessment are essential to the learner-centered, knowledge-centered, and assessment-centered classroom that establishes a community of science learners (Bransford, Brown, and Cocking 1999).

But what happens if students are unable to demonstrate understanding? What if students have a pretty good understanding about the diverse and robust roles of proteins in cells but struggle a bit to clearly link the role of proteins at the various levels of organization, resulting in the phenotype? What might now be done to provide additional instructional support?

We recommend that if the majority of students are still struggling with the concepts that you explicitly walk through the research process as a whole-class activity, using a disorder not previously studied by a student group. First, demonstrate to the class, using a think-aloud approach, how you would extract information from selected text and organize that information in an appropriate graphic organizer. Then give each small group text (or links to websites) that addresses the impact of the disorder at a different level of organization. After students read the text individually, they discuss the text in their small groups. The teacher then facilitates whole-class mapping using small-group input. This round of sense making models for students the use of informational text to perceive and organize information. It also demonstrates how to use concept mapping to organize and connect information. Students then can revisit their work on the original assigned trait, modifying their explanations. Thus, they extend and apply what they have just learned.

What happens if most of the students understand the basic ideas but a portion of students are still struggling to understand them? For those students who have mastered the basic ideas, we suggest that they work with the Concord Consortium materials (www.concord.org/resources/browse/172). This resource is rich with interactive experiences, and students should be able to explore further on their own without intensive teacher support. The teacher is then free to work with the small group of

students who do not yet understand the basic ideas. The teacher probes their thinking, perhaps using more-structured graphic organizers and reading extracts or simply has a small-group discussion to clarify ideas.

Reflection and Application

Before proceeding to the next learning targets, let's consider the process we just used and reflect on its application in your context. See Figure 6.7 and review Learning Target #1 in Table 6.1, page 185.

1. What about this iterative process makes sense to you? What works easily in your context?
2. What about this process makes your instruction difficult and why?
3. If challenges exist, how would you overcome those challenges?

Figure 6.7

Finalizing the Process to Promote Understanding

Use these steps to select and implement sense making and formative assessment strategies.

Strategy Selection

1. As before, review the Instructional Strategy Sequencing Tool (Instructional Tool 2.1, p. 29) to identify strategies for sense making, including
 - a. perceiving, interpreting, and organizing information,
 - b. connecting information,
 - c. retrieving, extending, and applying information, and
 - d. using knowledge in relevant ways.
2. Also review Instructional Tool 2.1 for potential formative assessment strategies.

Strategy Implementation

3. Implement the selected strategies for sense making in Instructional Tool 2.1 and gather data using the formative assessment strategies for a learning target.
4. If formative assessments indicate that all students understand the concepts, move forward with the next learning target.
5. If they do not understanding the ideas, then
 - a. use a different strategy to provide additional learning experiences for the students or
 - b. extend the learning for students who demonstrate understanding and provide additional small-group and/or individualized instruction for those who still struggle to understand.

Learning Targets #2–#4 (Table 6.1, pp. 186–188)

Learning Targets #2–#4 have several things in common. They all benefit from the use of dynamic modeling, primarily because dynamic models are effective for teaching abstract concepts and complex systems and connecting what happens at the submi-

microscopic and macroscopic levels (Calwetti 1999; Trunfio et al. 2003). Clearly, dynamic models will be helpful when you are teaching “genes and proteins.” Also, remember that we use expressed models to help our students develop mental models that align with scientific models.

What sense-making activities support the use of models? And what are some key, research-based ideas to keep in mind as we select strategies? Here are some important research findings to remember (see Instructional Tool 2.9 on p. 66 for a complete list of ideas):

- Conceptual development is enhanced if students are able to construct and critique their own models (Hipkins et al. 2002).
- Students who receive instructions and guiding questions along with a model better understand molecular genetics (Rotbain, Marbach-Ad, and Stavy 2005).
- An interactive dynamic model combined with scaffolding improves students’ abilities to explain human inheritance and evolutionary phenomena, connecting their ideas about phenotypes, chromosomes, and gametes (Schwendimann 2008).
- Simulations can promote misconceptions unless teachers work explicitly with students to identify limitations of the models (Calwetti 1999).
- Teachers should model scientific modeling to their students, encourage the use of multiple models in science lessons, and encourage negotiation of model meanings. Systematic presentation of in-class models using the Focus, Action, and Reflection (FAR) Guide to socially negotiate model meanings is effective (Harrison and Treagust 2000).

We recommend the following sense-making strategies to address these ideas:

- Written explanations that interpret dynamic models and text
- Group concept mapping that translates student experiences with the dynamic model into students’ own mental and written models
- Large- and small-group discourse to interpret and apply interactions with the models
- Comparison of interactive models and student concept maps with text (scientific explanations)
- Creating and critiquing analogies to extend and apply mental models, using the FAR Guide.²

In addition, Learning Target #4 requires students to make predictions (claims) about mutations, gather evidence using a protein folding interactive developed by the Concord Consortium, and use this evidence to further explain the impact of their chosen disorders. The development, critique, and support of these explanations address both “retrieving, extending and applying information” and “using knowledge in relevant ways” (as cited in Instructional Strategy Sequencing Tool 2.1).

As we consider ways for students to demonstrate understanding, we recall that the sense-making activities for Learning Targets #2–#4 include embedded formative assessments. In addition, student explanations in Learning Target #4 can be reviewed and critiqued by you, other students, and the students themselves. Critique of explanations is most effective when clear targets and rubrics that include the criteria for success are made available before instruction. Sutherland, McNeill, and Krajcik (2006) propose that the components of the rubric include a critique of the claim (that it responds to the question asked or problem posed), the evidence (that scientific data are used to provide support for the claim), and the reasoning (that students use scientific principles to explain why the data provide evidence to support the claim). Keeley (2008) describes a formative assessment strategy, “Explanation Analysis,” that builds on this thinking. It is an appropriate strategy because we expect students to develop quality scientific explanations.

Study Table 6.1, pages 186–188, to see how we apply the information in the table to sense making and demonstrating understanding for Learning Targets #2–4.

Chapter 6 has used “proteins and genes” as the context for focusing on aspects of the *responsive phase*, primarily on sense making. We considered how to select and implement formative assessments and demonstrated how these assessment data inform ongoing instruction. For the first time, we modeled the iterative nature of the *responsive phase*. Our chapter-by-chapter approach to modeling the implementation of our Instructional Planning Framework is now complete. In Chapter 7 we walk through the entire process, letting you see its application in full.

Table 6.1

Teacher Work Template for “Molecular Genetics: Proteins and Genes”

Lesson Topic—Molecular Genetics: Proteins and Genes		
Predictive Phase		
Conceptual Target Development	National Standard(s) Addressed	<p><i>From 9–12 NSES:</i></p> <ul style="list-style-type: none"> Cells store and use information to guide their functions. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires. (p. 184) In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular “letters”) and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome. (p. 185)
	Conceptual Learning	<p><i>From 9–12 Benchmarks:</i></p> <ul style="list-style-type: none"> The work of the cell is carried out by the many different types of molecules it assembles, mostly proteins. Protein molecules are long, usually folded chains made from 20 different kinds of amino-acid molecules. The function of each protein molecule depends on its specific sequence of amino acids and its shape. The shape of the chain is a consequence of attractions between its parts. (p. 114) The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. (p. 114)
	Previous Conceptual Learning	<p><i>From middle grade NSES:</i> Cells carry on the many functions needed to sustain life. They grow and divide, thereby producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organism needs. (p. 156)</p> <p><i>From middle grade Benchmarks:</i> Within cells, many of the basic functions of organisms...are carried out. The way in which cells function is similar in all living organisms. (p. 112)</p> <p><i>From prior instruction in the biology course:</i></p> <p><i>NSES:</i> In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular “letters”) and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome.</p> <p><i>Benchmarks:</i> Within the cells are specialized parts for the transport of materials, energy capture and release, protein building, waste disposal, passing information, and even movement.</p>

Table 6.1 (continued)

<p>Conceptual Target Development (cont.)</p>	<p>Knowledge and Skills</p> <p>Essential knowledge: See Learning Targets #1–#4 and unpack for embedded knowledge.</p> <p>Subtopics that may be pruned:</p> <ul style="list-style-type: none"> • Specific descriptions of how proteins function (e.g., enzyme catalysis, muscle contraction) • Details about transcription and translation • Names and structures of nucleotides • RNA and its structure • Primary, secondary, and tertiary structure of proteins • Differentiation between hydrophobic and hydrophilic amino acids. • Peptides and peptide bonds • Nucleic acids and nucleotides • Transcription and translation <p>Essential vocabulary: <i>protein, amino acid, gene, code, phenotype/trait.</i> Nucleotide, if used, should be followed by “a subunit of DNA.”</p> <p>Vocabulary that may be pruned: <i>peptide bond, polymer, ribosome, adenine, guanine, thymine, cytosine, purines, pyrimidines, ribonucleic acid, phosphate group, ribose, messenger RNA, transfer RNA, ribosomal RNA, codon</i></p>
<p>Essential Understandings</p>	<p>Proteins carry out the major work of cells but, if proteins are not made properly, cell function can be affected. Changes (mutations) in the gene/DNA can impact not only the code but also the protein, cells, and tissues. Though some mutations can be helpful, they might also stop or limit the proteins’ ability to function and potentially lead to physiological disorder in the organism.</p>
<p>Criteria to Demonstrate Understanding</p>	<ul style="list-style-type: none"> • Describe the central role of proteins and link the action of a particular protein across levels of organization (cell, tissue, organ, organism), explaining how an organism’s phenotype reflects the work of the protein. • Model how DNA coding determines the sequence of amino acids in a protein. • Illustrate how amino acid sequence determines the shape of a protein and correlate protein shape and function. • Determine the impact of a mutation on a phenotype/trait, including a discussion of the protein’s role in the process. • Make connections between personal explanations based on a protein synthesis simulation and scientific explanations of the process (standards-based focus). • Be open to others’ ideas to establish thinking about proteins and genes (metacognitive focus—creativity using brainstorming).

Responsive Phase

<p>Identifying Student Preconceptions</p>	<ul style="list-style-type: none"> • Use an anticipation/reaction guide and include common misconceptions about the relationship of proteins, genotype, and phenotype. Examples of anticipation guides can be found at www.gystc.org/6thGrdCur/documents/s6e2/c/es_1.pdf or www.ncrel.org/sdrs/areas/issues/students/learning/lr1anti.htm. • Use the response to the guide as a preparation for a preliminary discussion on one or more of the ideas. This discussion could be via a Socratic seminar, a jigsaw discussion, or small-group dialogue.
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Table 6.1 (continued)

Learning Sequence Targets	
Learning Target #1	Proteins carry out the major work of cells and are responsible for both the structures and functions of organisms. An organism's traits (phenotype) are a reflection of the work of proteins.
Research-Identified Misconceptions Addressed	
<ul style="list-style-type: none"> • It may be easier for students to understand the cell as the unit of structure than the cell as the unit of function (AAAS 1993). • Students demonstrate confusion over levels of organization, particularly with cells and molecules. They tend to think of molecules as related to the physical sciences and cells to life science. Some students even think that proteins are made of cells and that molecules of protein are bigger than cells (Driver et al. 1994). • Because students are not aware that proteins play a role that is central to living things (most/all genetic phenomena are mediated by proteins) and robust (many functions), it hampers their ability to provide mechanistic explanations of genetic phenomena (Duncan and Reiser 2005). • The majority of upper-division biology students and future science teachers recognize the physical constitution of an organism as its phenotype, yet do not understand the role of genes and proteins in producing the phenotype (Elrod n.d.). 	

Initial Instructional Plan

Eliciting Preconceptions: Facilitate a brainstorming session using the probe, "What are proteins and why are they important?" This can be as a whole-class or in small groups (but share as a whole class after small-group work). You can use one of the brainstorming webs (Instructional Tool 2.10, p. 72) or use the understanding routine, Think/Puzzle/Explore, found at the Visible Thinking website (see Instructional Tool 2.5, p. 44, Engage in Scientifically Oriented Questions). During the class discussion, elicit ideas about various proteins and introduce the concept that missing or ill-functioning proteins can significantly impact functions and, in many cases, cause disease. The goal is to ensure that students understand the robust and important functions of proteins. End the discussion by generating student questions.

Confronting Preconceptions: Show the YouTube video "Protein Functions in the Body" (see Recommended Resources at the end of this chapter). Provide student groups with a list of various proteins and the associated disorders that can arise if the protein is missing or malfunctioning. Have each group choose a disorder. Their task is to research the protein and disorder and determine the impact of the missing or malfunctioning protein on the various levels of organization (cells, tissues, organs, organisms). Model what this would look like, using sickle-cell anemia as an example (students revisit sickle cell in Learning Target #3). Do not focus on the actual mutation, but on the impact of sickle cell at the various levels of organization. Two resources that students can use as a starting point is a summary of disorders (www.usoe.k12.ut.us/CURR/SCIENCE/core/bio/genetics/home%20page.htm) and a resource at the Your Genes, Your Health website (www.ygyh.org).

Sense Making: Review with students the use of two-column notes and tree maps before they begin research. Facilitate their use during small-group work, probing for student understanding of both concepts and use of the tools. Require students to prepare both individual summaries in their learning logs, share and critique their summaries (as a group), and prepare a poster presentation to share with the entire class. Support students during individual learning log summary development and during poster preparation. Use a round-robin approach to poster sharing, during which students rotate from poster to poster, critiquing the work, looking for similarities and differences among posters, and generating questions. Facilitate a whole-class discussion, summarizing key ideas, and generating questions (poster paper or SmartBoard).

Table 6.1 (continued)

Formative Assessment Plan (Demonstrating Understanding)

- Teacher review of learning logs, including two-column notes
- Analysis of tree maps for inclusion of key ideas
- Questions and probes during small-group work and class discussion
- Final posters and poster critiques using pre-established rubrics

Learning Target #2	Genetic information (genes) coded in DNA provides the information necessary to assemble proteins. The sequence of subunits (nucleotides) in DNA determines the sequence of amino acids in proteins.
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Research-Identified Misconceptions Addressed

- Some students think a gene is a trait or that the DNA makes proteins (Elrod n.d.).
- Because some students do not connect genes to proteins to phenotypes (Lewis and Wood-Robinson 2000), they assume that genes directly express traits in organisms (Lewis and Kattmann 2004).
- Less than half of upper-division biology students and future science teachers understand the nature of the genetic code (Elrod 2007). Only 22% of undergraduate students with some biological science course work defined the gene in terms of nucleotide sequences involved in protein synthesis (Chattopadhyay and Mahajan 2006).
- Though students usually equate genes with traits, they do not understand that genes code for specific proteins and that the production of these proteins results in the traits (Friedrichsen and Stone 2004).
- Students often think that genes code for more than proteins. They also often think that the genes code for information at multiple levels of organization (e.g., the gene “tells” a tissue or organ to malfunction), which bypasses the need for students to provide a mechanistic explanation of molecular genetics phenomena (Duncan and Reiser 2005).
- 30–52% of upper-division biology students and future science teachers do not recognize RNA as the product of transcription. 50–75% of introductory biology and genetics students in college and future science teachers do not identify proteins as the product of translation (Elrod 2007; Fisher 1985).

Initial Instructional Plan

Eliciting Preconceptions: Begin with the idea that all the work students just completed was about genetic disorders. Ask them how genes are related to the proteins just studied. Provide students with a list of the essential vocabulary terms and ask them to use all the terms in the list to write their best explanations of the relationship. Share in small groups and then discuss selected explanations as a whole class. Now share an animation that provides an overview of protein synthesis (see Resources, below). Have small groups discuss and map connections to previous understandings, interpretations of the overview, and any questions they have. Facilitate discussions in small groups and then as whole class, focusing on the ideas in the learning target.

Confronting Preconceptions: Have students read about protein synthesis from their text or other print resource and modify their maps and explanations based on what they learn. Next, have them complete a shockwave activity available at the DNA Workshop site, choosing the protein synthesis option (see Resources, below) or one of the activities at the Concord Consortium’s Molecular Logic Project (see Resources, below). Note that students are not responsible for all vocabulary used in either resource, unless this is expected in your school district. The idea is to provide visual images of the connection between genes and proteins.

Sense Making: Have students revisit concept maps, explanations, and questions, revising based on new experiences. Assign to students sections of text (print/electronic sources) on protein synthesis. Once again, have them modify concept maps and explanations. Facilitate the work of each group with probes and questions. Then use student questions as guides for class discussion.

Table 6.1 (continued)

Formative Assessment Plan (Demonstrating Understanding)

- Questions and probes during small-group work and class discussion
- Analyze student explanations using a rubric
- Analyze student concept maps (peer critique of maps can also be included)
- Use student questions to indicate ongoing areas of misunderstanding and elicit ideas using questions as a guide for class discussion

Learning Target #3	The sequence of amino acids determines not only the kind, but also the shape, of the protein, and thus its function.
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Research-Identified Misconceptions Addressed

- It may be easier for students to understand the cell as the unit of structure than the cell as the unit of function (AAAS 1993).
- Many students think that a gene is a trait or that the DNA makes proteins (Elrod 2007).
- Though students usually equate genes with traits, they do not understand that genes code for specific proteins and that the production of these proteins results in the traits (Friedrichsen and Stone 2004).
- Though 80% of undergraduates knew that a disease could be linked to a gene, only 35% correctly represented a flow diagram between the genes and disease. Even if they could explain the concept of the central dogma, they could not extrapolate their understanding to a real-life situation (Chattopadhyay and Majahan 2006).

Initial Instructional Plan

Eliciting Preconceptions: Go to <http://molo.concord.org/database/activities/76.html> and show “How a Protein Gets Its Shape: The Role of Charge.” Run the “original chain” as a demonstration, also showing how the simulation works. Share your mental model of the process, thinking out loud. Have students run the additional demonstrations (individual or with a partner). Then have them discuss, in small groups or as partnered problem solving (see Table 2.4, p. 39, Classroom Implications for Talk About Thinking), why they think protein shape is important. Share ideas with the whole class and facilitate a discussion.

Confronting Preconceptions: Go to <http://molo.concord.org/database/activities/225.html> and have students complete “Protein Folding: Stepping Stones Full Interactive,” screens #1–#4. As they complete the activities, they generate a report that is submitted at the end of the activity. However, this will not be complete until after Learning Target #4.

Sense Making: Model for students how to develop an analogy for protein synthesis. Make sure to identify the concept and the analog, discuss how the two are similar and how they are different, and reflect on the effectiveness of the analogy. What about it was effective and what was confusing? “Building a house” is one analog for protein synthesis, recommended by Harrison and Coll (2008). They outline an application of the FAR Guide in their book (see Resources, below). Once you model this, have students identify and develop an analogy.

Formative Assessment Plan (Demonstrating Understanding)

- Questions and probes during small-group work and class discussion
- Even though the student reports for the protein-folding interaction are not complete until the completion of Learning Target #4, you can review student work online during the interactions and use this information to gauge level of understanding
- Critiques of student analogies by self, peers, and teacher, using the FAR Guide if available

Table 6.1 (continued)

Learning Target #4	Mutations, changes in the DNA, impact protein production. Errors in the DNA (mutation) can result in missing proteins or ones that function inadequately. This results in a change in phenotype/trait.
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Research-Identified Misconceptions Addressed

- It may be easier for students to understand the cell as the unit of structure than the cell as the unit of function (AAAS 1993).
- Most students are unable to explain a situation where a change to the DNA sequence does not change the protein sequence (Eklund et al. 2007).

Initial Instructional Plan

Eliciting Preconceptions: Have students continue the protein-folding activity started in Learning Target #3. It now introduces mutation, focusing on sickle-cell anemia. Students are asked to predict the impact of a change to the DNA sequence before completing the simulation. Have them make this prediction (claim) and share their explanations as a class. Recall that scientific explanations require students to make claims, provide evidence for their claims, and link the claims to the evidence.

Confronting Preconceptions: Have students complete screens #5–#8. They can now complete and generate their report. They can also complete the activity, Modeling Mutations, further described at www.concord.org/publications/newsletter/2004-spring/mondayslesson.html.

Sense Making: Then have students refer to their textbooks or other print resources to research other types of mutations and their potential impact. They should connect this information back to their original research on their selected disorder. They should also revise their explanations and expand their analogies developed during Learning Target #3 to include what they learned in this part of the lesson.

Formative Assessment Plan (Demonstrating Understanding)

- Questions and probes during small-group work and class discussion
- Student reports generated by the protein-folding interaction
- Critique of scientific explanations by students and teacher (see description in text) or using the “Explanation Analysis” strategy (Keeley 2008)
- Critiques of student analogies by self, peers, and teacher, using the FAR Guide if available

Recommended Resources

Technology Applications and Websites

- The YouTube video “Protein Functions in the Body” (www.youtube.com/watch?v=T500B5yTy58) presents the wide array of proteins that make up living organisms.
- Two resources that students can use as a starting point as they research different disorders are www.usoe.k12.ut.us/CURR/SCIENCE/core/bio/genetics/home%20page.htm and Your Genes, Your Health website (www.ygyh.org).

- Teachers Domain (www.teachersdomain.org) offers a flash interactive—Cell Transcription and Translation—that includes an overview of protein synthesis as well as more detailed interactions with transcription and translation (www.teachersdomain.org/resource/lsp07.sci.life.stru.celltrans); at this point, we recommend sharing only the overview, not the details. If you do not have a Teachers Domain account, you can register at no cost.
- The DNA Workshop site (www.pbs.org/wgbh/aso/tryit/dna/#) has a protein synthesis shockwave. Also, more extensive explorations are available at the Concord Consortium’s Molecular Logic Project (<http://molo.concord.org>). Many of the explorations are linked to specific biology textbooks, perhaps including one your district uses.
- For your personal content learning, the NSTA SciPack “Cell Structure and Function” is a good option. In particular, the last Science Object called “The Most Important Molecule” relates directly to this chapter. Visit the NSTA Science Store (www.nsta.org/store/?lid=tnavhp) and search for “protein.”

Build Your Library

- A great resource for formative assessments, which we used to construct the Instructional Planning Framework, is *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2008). You might also consider any or all of the three *Uncovering Student Ideas in Science* volumes (Keeley, Eberle, and Farrin 2005; Keeley, Eberle, and Tugel 2007; Keeley, Eberle, and Dorsey 2008).
- An excellent resource to learn more about the use of analogies in secondary science classrooms is *Using Analogies in Middle and Secondary Science Classrooms: The FAR Guide—An Interesting Way to Teach With Analogies* (Harrison and Coll 2008).
- Chapter 11, “How Nature Builds Itself: Self-Assembly,” in *Nanoscale Science: Activities for Grades 6–12* (Jones et al. 2007), ties in nicely with some of the Concord Consortium dynamic models used in this lesson.
- Black and Harrison (2004) provide examples and suggestions for descriptive feedback for students in *Science Inside the Black Box: Assessment for Learning in the Science Classroom*.

Endnotes

1. The same resources used in previous chapters were used to determine appropriate standards; prior understandings; knowledge, skills, and vocabulary to include or exclude; and the learning targets. The identified learning sequence was based on three different resources: Roseman et al. (2006); Duncan, Rogat, and Yarden (2007); and Eklund et al. (2007).
2. The FAR Guide has three main aspects:
 1. Consider the focus. Look at the concept itself (difficult? unfamiliar? abstract?), the ideas the students bring to the table, and whether the analog is familiar to students.

2. What is the action? Discuss how the concept is like the analog (similarities) and unlike the analog (differences).
3. Take time to reflect. After using the analog, determine if it was clear or confusing and if it achieved the desired outcomes. Also consider any changes you would make in future use.

We urge you to learn more about the entire FAR Guide process prior to implementation. This summary, in itself, is not adequate for implementation.